DESCRIPTION

IMPROVED PARAMETER ESTIMATION FOR USE IN RADIO RANGING SYSTEMS

The present invention relates to improved parameter estimation for use in radio ranging systems. Such systems may comprise positioning systems using multiple antennas, MIMO systems, systems for determining distances between base stations having multiple antennas and any of the foregoing embodied in mobile receivers.

In a multipath environment, a transmitted radio signal is reflected from reflecting surfaces and is received at a receiver by way of more than one propagation path. Two of the characteristics of multipath are (1) a multipath will always arrive after the direct path signal because it must travel a longer propagation path, and (2) the multipath signal will normally be weaker than the direct path signal since some of the signal power will be lost from the reflection. The multipath signal can be stronger if the direct path signal is hindered in some way.

The various components or parameters of the signal received by way of different paths have different amplitudes (a_n), phases (θ_n) and delays (τ_n), which can make the information extracted from the composite received signal unreliable. For example, if the signal conveys data, the data error rate can be degraded, especially for high bit rate transmission, and if the signal is used for range estimation, the accuracy of the range estimate can be degraded. If the multipath properties of the radio signal can be characterised, the detrimental effects of multipath propagation can be reduced, for example by cancelling out unwanted reflections or by combining the signal received via different paths in a constructive manner. Also there are systems that use multi-element antennas (MEA) to achieve very high bit rate transmission. Such systems employ a characterisation of the multipath properties of the radio signal. An MEA system is described in "Layered Space-Time Architecture for Wireless

Communication in a Fading Environment When Using Multi-Element Antennas", G.J. Foschini, Bell Systems Technical Journal, Autumn 1996, pp. 41-59.

One approach to characterising multipath propagation is the use of parameter estimation techniques such as the Multipath Estimating Delay-Lock Loop (MEDLL) (see, for example, "Performance Evaluation of the Multipath Estimating Delay Lock Loop", B. Townsend, D.J.R. van Nee, P. Fenton, and K. Van Dierendonck, Proc of the Institute of Navigation National Technical Meeting, Anaheim, California, Jan. 18-20, 1995, pp. 227-283) and the Minimum-Mean-Square-Estimator (MMSE) (see, for example, "Conquering Multipath: The GPS Accuracy Battle", L.R. Weill, GPS World, April 1997). In parameter estimation techniques, the received signal is represented by a mathematical model, for example a model that includes variable parameters representing the amplitude (a_n), phase (θ_n) and delay (τ_n) of the signal components received via a plurality of propagation paths, and the parameter values are adjusted iteratively until a good match is obtained between the received signal and the mathematical model.

Generally techniques for doing accurate range measurements require a great many parameters and are therefore inefficient or inaccurate.

It is an object of the present invention to improve on the estimation of parameters to be used in any parameter estimation technique, for example MMSE and MEDLL.

According to a first aspect of the present invention there is provided a method of determining the value of a reflection coefficient to be used in estimating range in a radio ranging system, comprising transmitting an omnidirectional signal, spatially sampling received back scatter, deriving from a scaled received radar signal bounds of at least one reflection coefficient used in estimating range, spectral analysing the signal power density of a received signal to determine the number of specular reflections and values of the corresponding reflection coefficients, and matching the bounds of the at least one reflection coefficient with the spectral coefficient values derived from

the spectral analysis of the signal power of the received signal and using the spectral coefficient values to reduce the bounds of the at least one reflection coefficient to a more precise value.

According to a second aspect of the present invention there is provided a method of determining the value of a reflection coefficient to be used in estimating range in a radio ranging system, comprising transmitting an omnidirectional signal, spatially sampling received back scatter, scaling received radar back scatter to derive a bound of at least one parameter of multipath reflection, deriving a power versus distance profile at the receiver, Fourier Transforming the power versus distance profile to a spatial versus frequency domain spectrum, noting non-zero frequency spectral peaks in the spatial versus frequency domain spectrum due to specular reflections, matching the bound of the at least one parameter of multipath reflection with reflection coefficients derived from spectral analysis of the power versus spatial frequency domain to obtain more precise values of the at least one parameter and using a plurality of multipath components predicted from the signal power density.

According to a third aspect of the present invention there is provided a method of estimating range using a plurality of parameters, comprising transmitting an omnidirectional signal, spatially sampling received back scatter, deriving from a scaled, received radar signal bounds of at least one reflection coefficient used in estimating range, spectral analysing the signal power density of a received signal to determine the number of specular reflections and values of the corresponding reflection coefficients, matching the bounds of the at least one reflection coefficient with the spectral coefficient values derived from the spectral analysis of the signal power of the received signal, using the spectral components to reduce the bounds of the at least one reflection coefficient to a more precise value and using a plurality of multipath components predicted from the signal power density for parameter estimation.

According to a fourth aspect of the present invention there is provided a method of estimating range using a plurality of parameters, at least one of the parameters being determined by transmitting an omnidirectional signal,

spatially sampling received back scatter, scaling received radar back scatter to derive a bound of at least parameter of multipath reflection, deriving a power versus distance profile, Fourier Transforming the power versus distance profile to a spatial versus frequency domain, noting non-zero frequency spectral peaks in the spatial versus frequency domain spectrum due to specular reflections, matching the bound of the at least parameter of multipath reflection with reflection coefficients derived from spectral analysis of the power versus spatial frequency domain to obtain more precise values of the at least one parameter and using a plurality of multipath components predicted from the signal power density for parameter estimation.

According to a fifth aspect of the present invention there is provided a range measuring system comprising means for determining a plurality of parameters to be used in estimating range, said means including a transmitter for transmitting an omnidirectional signal, means for spatially sampling received back scatter, means for scaling received radar back scatter to derive a bound of at least one parameter of multipath reflection, means for deriving a power versus distance profile, means for Fourier Transforming the power versus distance profile to a spatial versus frequency domain spectrum, means for noting non-zero frequency spectral peaks in the spatial versus frequency domain spectrum due to specular reflections, means for matching the bound of the at least one parameter of multipath reflection with reflection coefficients derived from spectral analysis of the power versus spatial frequency domain to obtain more precise values of the at least one parameter, and means for determining the number of multipath components for parameter estimation.

In the method in accordance with the present invention by using spectral analysis in combination with radar (or sounding) information, it is possible achieve improved algorithmic accuracy and efficiency of a parameter estimation technique for multipath mitigation.

The present invention will now be described, by way of example, with reference to the accompanying drawings, wherein:

Figure 1 is a block schematic diagram of a radio system in a multipath environment,

Figure 2 is a flow chart relating to the operations of a radio station in the system shown in Figure 1,

Figure 3 is a diagram illustrating the geometry of the multipath scenario of Figure 1,

Figure 4 is a graph of distance versus power in respect of the signals received at the equally spaced antennas 24A to 24D in Figure 1, and

Figure 5 is a graph of frequency versus power showing non-zero spectral peaks.

In the drawings the same reference numerals have been used to indicate corresponding features.

For convenience of description, the present invention will be described with reference to MEDLL.

According to MEDLL the received signals *r(t)* at the input of a receiver can be written:

$$r(t)=\sum_{n}^{M} a_n e^{j\theta_n} s(t-\tau_n)+n(t) \qquad (1)$$

where a_n is amplitude,

θ_n is phase,

τ_n is time delay,

s(t) is the transmitted signal,

n(t) is noise and

M is the total number of specular reflections.

The present invention has particular, but not exclusive, application to improving the estimation of all the parameters as using better initial estimates of amplitude (a_n) and the number of multipath components improves the accuracy of all the parameter estimates as well as speeding up the process.

In equation (1), the terms a_n, θ_n and τ_n can be determined by minimising the noise term *n(t)*.

In a situation of receiving data *D(t)* then in accordance with the MEDLL if the noise term is a random variable with the non-zero Gaussian distribution then $\sum_t n(t) = 0$.

As a result, the mean square error between the signal components and the received signal is:

$$\sum_t \left[D(t) - \sum_{n=0}^{M} a_n e^{j\theta_n} s(t-\tau_n) \right]^2 = \sum_t [n(t)]^2 = 0 \qquad (2)$$

By minimising this expression one has a non-linear problem giving non-unique solutions.

By having prior estimates of the parameters a_n, θ_n and τ_n, characterising the multipath components according to the MEDLL or MMSE (i) it would work faster and thus be able to include more parameter values for greater accuracy and (ii) is more likely to find the correct solution to the non-linear problem.

Referring to the radio system of Figure 1, a first radio station 10 comprising a first transceiver 12 is coupled to a first antenna 14 and to a first processing means 16. A storage means 18 is coupled to the first processing means 16 for the temporary storage of data. A second, target station 20 comprising a second transceiver 22 is coupled to a plurality, for example four, equally spaced second antennas 24A to 24D. A second processing means 26 is coupled to the second transceiver 22 and a second storage means 28 is coupled to the second processing means 26 for the temporary storage of data. Both transceivers 12, 22 are equipped to communicate using spread spectrum signalling. Also illustrated in Figure 1 are first and second reflecting surfaces 40, 50 which may be, for example, walls. In a practical scenario there may be more reflecting surfaces but for clarity only two are illustrated in Figure 1.

In operation the first station 10 transmits an omnidirectional signal. Radar signals S1 and S2 which are reflected by the reflecting surfaces back to the antenna 12 are retained and are used by the first processing means to determine the position of the first station relative to the reflecting surfaces 40,

50 and includes this information in the omnidirectional signals. If the first station is fixed then it will not be necessary to repeatedly determine its relative position. At the second station signals, which may be the subject of multipath, are received by the antennas 24A to 24D. For convenience of illustration a line-of-sight (LOS) signal 42 and two reflected or multipath signals 44, 46 are shown.

The second processing means 26 computes the range using parameter values, one or more of which are determined by the method in accordance with the present invention. These and other parameter values are substituted into a range estimating equation such as MEDLL.

The flow chart shown in Figure 2 summarises the method in accordance with the present invention. The method provides an algorithm for improved multipath estimation by at least employing spectral analysis of the signal power density for a mobile receiver or multiple antenna system. This determines the number of specular reflections along with the value of reflection coefficients. The algorithm uses the power density information at each antenna of the multi-antenna receiver together with radar information S1 and S2 in order to improve the efficiency or accuracy of parameter estimation of the multipath signals. The technique processes instantaneous information of the environment to aid any system that requires knowledge of the channel.

Referring to Figure 2, block 60 relates to the first transceiver 12 transmitting an omnidirectional signal. Block 62 relates to the first station 10 retaining the radar back-scatter S1, S2 and including this information in a subsequent omnidirectional signal for use in the computations done by the processing means in the second station 20. Block 64 relates to the multipath reflections being scaled by a process to be described later. Block 66 relates to the second processing means determining bounds for the amplitude a_n and delays τ_n of the multipath reflections from the scaled radar back-scatter.

Block 68 relates to the multiple antennas 24A to 24D receiving the power-distance profile and block 70 relates to the power-distance profile at each antenna being transformed to the spatial-frequency domain. Block 72 relates to examining the transformed profile for delta functions (otherwise

termed the peaks) occurring at non-zero frequencies due to the specular reflections. The value of the frequency it occurs at is proportional to the sum of the phase difference between the direct and indirect fields and the Doppler frequency difference between the direct and indirect fields. Block 74 relates to deriving the reflection coefficients of the specular reflections from the power (or height) of the delta functions and the total number of specular reflections M (Equations 1 and 2) from the total number of delta functions.

Block 76 relates to matching the reflection coefficients bounds a_n and τ_n found by way of radar and their delays (block 66) with those from the spectral analysis of the power versus spatial frequency domain. Block 78 relates to reducing the amplitude bounds to more precise numerical values for the amplitudes and matched with their respective delay bounds. The total number of specular reflections or delta functions is known and can be used in parameter estimation. Block 80 relates deriving a diffuse background function from the total number of specular reflections and adding it to the computations at the correct juncture.

Block 82 relates to using the antennas 24A to 24D as a phased array to propagate a radar signal which will yield further information such as the size and shape of the local reflectors for a mapping procedure.

Referring to Figure 3 which shows an omnidirectional ranging signal transmitted by the second station 20 and received by the first station and a radar signal transmitted laterally to the reflecting surfaces 40, 50. The length of the direct (or LOS) path is d_0 and the lengths of two reflected paths are d_1, that is (d_{1A} + d_{1B}), and d_2 , that is (d_{2A} and d_{2B}). The lengths of the radar paths S1 and S2 is half their respective round trip distances $d_{b1}/ 2$ and $d_{b2}/ 2$. The angles of arrival of the LOS path d_0 and a line perpendicular to the reflecting surface are φ_1 and φ_2, respectively.

From Figure 4 it can be deduced that:

$$d_1 = d_{1A} + d_{1B} = \sqrt{d_0^2 + 4 d_0 d_{b_1} \cos\varphi_1 + d_{b1}^2}$$

$$d_2 = d_{2A} + d_{2B} = \sqrt{d_0^2 + 4 d_0 d_{b_2} \cos\varphi_2 + d_{b_2}^2}$$

These equations can be generalised so that the distance d_k can be expressed by the equation:

$$d_k = \sqrt{d_0^2 + d_0 d_{b_k} \cos\varphi_k + d_{b_k}^2}, \text{ for } k > 0 \quad (3)$$

where φ_k is the angle of arrival of the signal received via the direct path and d_0 is the direct path distance. The angle of arrival φ_k is defined as the angle between the direct path and a line perpendicular to the *kth* reflecting surface, such that the angle is not intersected by the *kth* reflected path, as shown in Figure 3.

The model of the received radar signal correlation function is scaled in time and amplitude, by the first processing means 16, to approximate the reflected signal that would be received if the radar signal had been transmitted from the second station 20. In order to scale in time, each d_{b_k} in equation (3) is replaced by the distance d_k travelled if the signal contributing to that sample had travelled from the second station 20 via the same reflecting surface. Analysis of the multipath geometry illustrated in Figure 3 shows that the distance d_k travelled by a signal transmitted by the second station 20 and received at the radio station 10 via a *kth* reflecting surface can be expressed as

$$d_k = \sqrt{d_0^2 + d_0 d_{b_k} \cos\varphi_k + d_{b_k}^2} \quad \text{for } k > 0 \quad (4)$$

In order to scale the amplitude, each sample amplitude a_{b_k} is replaced by the amplitude a_k that the sample would have if the signal had travelled from the target station 20 via the same reflecting surface. Using the generally accepted inverse fourth power law for the attenuation with distance travelled, a_{b_k} can be represented as

$$a_{b_k} = \frac{B\mu_k}{d_{b_k}^{\ 2}} \quad \text{for } k>0 \quad (5)$$

where B is the amplitude of the transmitted sounding signal and μ_k is the reflectivity of the reflecting surface, and a_k can be represented as

$$a_k = \frac{A\mu_k}{d_k^2} \qquad \text{for } k>0 \tag{6}$$

where A is the amplitude of transmissions from the target station 20.
Combining equations (3), (5) and (6) gives

$$a_k = \frac{A a_{b_k} d_{b_k}^2}{B\left(d_0^2 + d_0 d_{b_k} \cos\varphi_k + d_{b_k}^2\right)} \qquad \text{for } k>0 \tag{7}$$

Replacing d_{b_k} in equation (3) by the expression of equation (5), and a_{b_k} in equation (5) by the expression of equation (6) gives the following expression for the scaled model of the received sounding signal correlation function, i.e. a model representing a signal transmitted by the second station 20 and received at the first station 10:

$$R_{b\,scaled}(\tau) = \sum_{k=1}^{K} \frac{A a_{b_k} d_{b_k}^2}{B\left(d_0^2 + d_0 d_{b_k} \cos\varphi_k + d_{b_k}^2\right)} F_b\left(\frac{\sqrt{d_0^2 + d_0 d_{b_k} \cos\varphi_k + d_{d_{b_k}}^2}}{c}\right) \tag{8}$$

$R_{b_{scaled}}(\tau)$ comprises measured data, referred to as radar data, derived from the received sounding signal and some parameters having unknown values,

$F_b(\tau_k)$ is the correlation peak with the peak centred at τ_k and width $2T_c$ (that is double chip width).

A numerical example will now be given with a view to facilitating a greater understanding of the method in accordance with the present invention. Figure 4 is a graph of distance (abscissa) versus power (ordinate) of the back scatter received by the antennas 24A to 24D (Figure 1). Figure 5 shows the Fourier Transform of distance versus power graph shown in Figure 4 to obtain the power density spectrum in k-space and illustrates non-zero frequency spectral peaks.

D(t) is the received signal data.

$\sum_{t} D(t) s(t-\tau) = K(t)$ is the received correlation function.

To obtain initial estimates of parameters:

$$K(\tau) = F_b scaled(\tau) + a_o e^{j\theta_0} F_b(\tau_0)$$

where $K(\tau)$ is data.

This equation is solved for d_0 and φ_k, a_0 and θ_0.

From d_0 and φ_k we obtain a_k and d_k from equations (7) and (4) above.

So from scaled back scatter we obtain initial estimates of a_0, θ_0, d_0, φ_k, a_k and d_k for all components.

Examining the spectral peaks shown in Figure 5, values for amplitudes $a_1,\ldots a_n$ can be obtained. The amplitudes are matched and the more accurate value derived from the spectral analysis is used in the subsequent range estimation.

Although the embodiment shown in Figure 1 shows the second station 20 having a plurality of equally spaced antennas, an alternative possibility would be for the second station 20 to have one antenna and move at a constant speed and the received signal being sampled spatially at equal time increments.

Reference is made to International Patent Applications IB 02/02734 (Applicant's reference PHGB 010139) which relates to accurate range and angle of arrival measurement from dominant reflection information and IB 02/02735 (Applicant's reference PHGB 010140) which relates to accurate range and angle of arrival measurement from scaled back-scatter data, details of which patent applications are incorporated into the present application by way of reference.

In the present specification and claims the word "a" or "an" preceding an element does not exclude the presence of a plurality of such elements. Further, the word "comprising" does not exclude the presence of other elements or steps than those listed.

From reading the present disclosure, other modifications will be apparent to persons skilled in the art. Such modifications may involve other

features which are already known in the design, manufacture and use of radio ranging systems and component parts therefor and which may be used instead of or in addition to features already described herein. Although claims have been formulated in this application to particular combinations of features, it should be understood that the scope of the disclosure of the present application also includes any novel feature or any novel combination of features disclosed herein either explicitly or implicitly or any generalisation thereof, whether or not it relates to the same invention as presently claimed in any claim and whether or not it mitigates any or all of the same technical problems as does the present invention. The applicants hereby give notice that new claims may be formulated to such features and/or combinations of such features during the prosecution of the present application or of any further application derived therefrom.

CLAIMS

1. A method of determining the value of a reflection coefficient to be used in estimating range in a radio ranging system, comprising transmitting an omnidirectional signal, spatially sampling received back scatter, deriving from a scaled, received radar signal bounds of at least one reflection coefficient used in estimating range, spectral analysing the signal power density of a received signal to determine the number of specular reflections and values of the corresponding reflection coefficients, and matching the bounds of the at least one reflection coefficient with the spectral coefficient values derived from the spectral analysis of the signal power of the received signal and using the spectral coefficient values to reduce the bounds of the at least one reflection coefficient to a more precise value.

2. A method of determining the value of a reflection coefficient to be used in estimating range in a radio ranging system, comprising transmitting an omnidirectional signal, spatially sampling received back scatter, scaling received radar back scatter to derive a bound of at least one parameter of multipath reflection, deriving a power versus distance profile at the receiver, Fourier Transforming the power versus distance profile to a spatial versus frequency domain spectrum, noting non-zero frequency spectral peaks in the spatial versus frequency domain spectrum due to specular reflections, matching the bound of the at least one parameter of multipath reflection with reflection coefficients derived from spectral analysis of the power versus spatial frequency domain to obtain more precise values of the at least one parameter and using a plurality of multipath components predicted from the signal power density.

3. A method as claimed in claim 2, characterised in that the spatial sampling is effected using a plurality of spatially separated antennas.

4. A method as claimed in claim 2 or 3, characterised in that the bounds of at least two parameters are derived.

5. A method as claimed in claim 4, characterised in that the at least two parameters are amplitude ($a_{n)}$ and time delay (τ_n).

6. A method of estimating range using a plurality of parameters, comprising transmitting an omnidirectional signal, spatially sampling received back scatter, deriving from a scaled, received radar signal bounds of at least one reflection coefficient used in estimating range, spectral analysing the signal power density of a received signal to determine the number of specular reflections and values of the corresponding reflection coefficients, matching the bounds of the at least one reflection coefficient with the spectral coefficient values derived from the spectral analysis of the signal power of the received signal, using the spectral components to reduce the bounds of the at least one reflection coefficient to a more precise value and using a plurality of multipath components predicted from the signal power density for parameter estimation.

7. A method of estimating range using a plurality of parameters, at least one of the parameters being determined by transmitting an omnidirectional signal, spatially sampling received back scatter, scaling received radar back scatter to derive a bound of at least parameter of multipath reflection, deriving a power versus distance profile, Fourier Transforming the power versus distance profile to a spatial versus frequency domain, noting non-zero frequency spectral peaks in the spatial versus frequency domain spectrum due to specular reflections, matching the bound of the at least parameter of multipath reflection with reflection coefficients derived from spectral analysis of the power versus spatial frequency domain to obtain more precise values of the at least one parameter and using a plurality of multipath components predicted from the signal power density for parameter estimation.

8. A method as claimed in claim 7, characterised in that the bounds of at least two parameters are derived.

9. A method as claimed in any one of claims 7 or 8, characterised in that received signals (r(t)) are estimated using an equation

$$r(t)=\sum_{n}^{M}a_n e^{j\theta_n}s(t-\tau_n)+n(t) \qquad (1)$$

where a_n is amplitude,

θ_n is phase,

τ_n is time delay,

s(t) is the transmitted signal,

n(t) is noise and

M is the total number of specular reflections.

10. A range measuring system comprising means for determining a plurality of parameters to be used in estimating range, said means including a transmitter for transmitting an omnidirectional signal, means for spatially sampling received back scatter, means for scaling received radar back scatter to derive a bound of at least one parameter of multipath reflection, means for deriving a power versus distance profile, means for Fourier Transforming the power versus distance profile to a spatial versus frequency domain spectrum, means for noting non-zero frequency spectral peaks in the spatial versus frequency domain spectrum due to specular reflections, means for matching the bound of the at least one parameter of multipath reflection with reflection coefficients derived from spectral analysis of the power versus spatial frequency domain to obtain more precise values of the at least one parameter, and means for determining the number of multipath components for parameter estimation.

11. A method of determining the value of a reflection coefficient to be used in estimating range in a radio ranging system, substantially as hereinbefore described with reference to the accompanying drawings.

12. A method of estimating range using a plurality of parameters, substantially as hereinbefore described with reference to the accompanying drawings.

13. A range measuring system constructed and arranged to operate substantially as hereinbefore described with reference to and as shown in the accompanying drawings.

ABSTRACT

IMPROVED PARAMETER ESTIMATION FOR USE IN RADIO RANGING SYSTEMS

A method of determining the value of a reflection coefficient and the number of multipath components to be used in estimating range in a multipath environment, comprises transmitting an omnidirectional signal, spatially sampling (24A to 24D) received back scatter (44, 46), deriving from a scaled, received radar signal amplitude (a_n) and time delay (τ_n) bounds of reflection coefficients used in estimating range, Fourier Transforming a received power-distance profile to the spatial-frequency domain, spectrally analysing the signal power density of a received signal to determine the number of specular reflections and values of the corresponding reflection coefficients, and matching the bounds of the reflection coefficients with the spectral coefficient values derived from the spectral analysis of the signal power of the received signal and reducing the bounds of the at least one reflection coefficient to a more precise value by using the spectral coefficient values for range estimation.

(Figure 1)

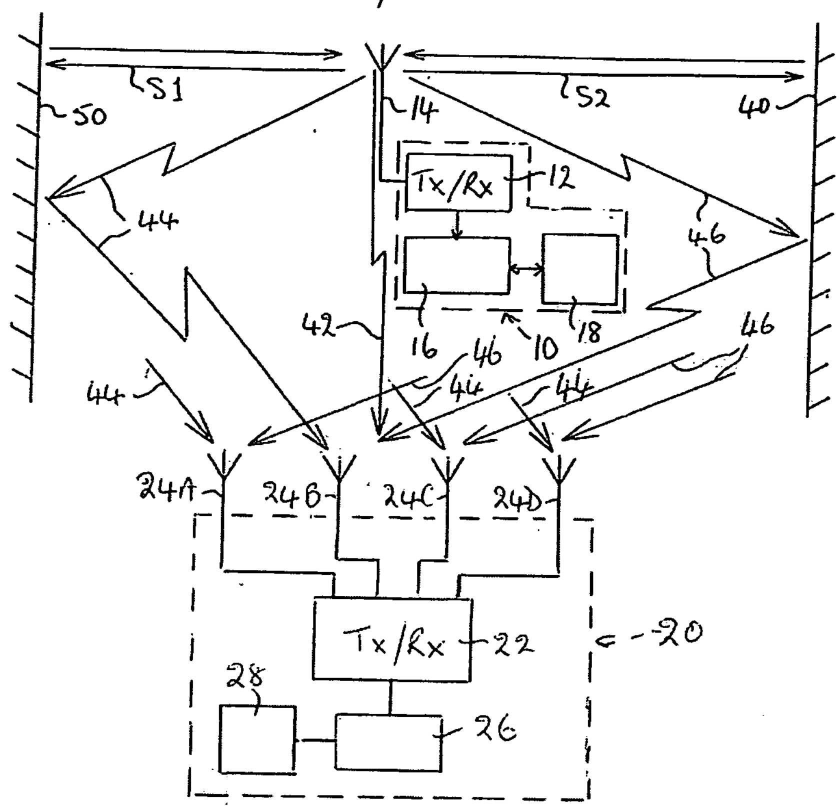

S1
S2
50
40
14
Tx/Rx
12
44
46
42
16
10
18
Tx/Rx
22
20
24A
24B
24C
24D
28
26

Fig. 1

10/525331

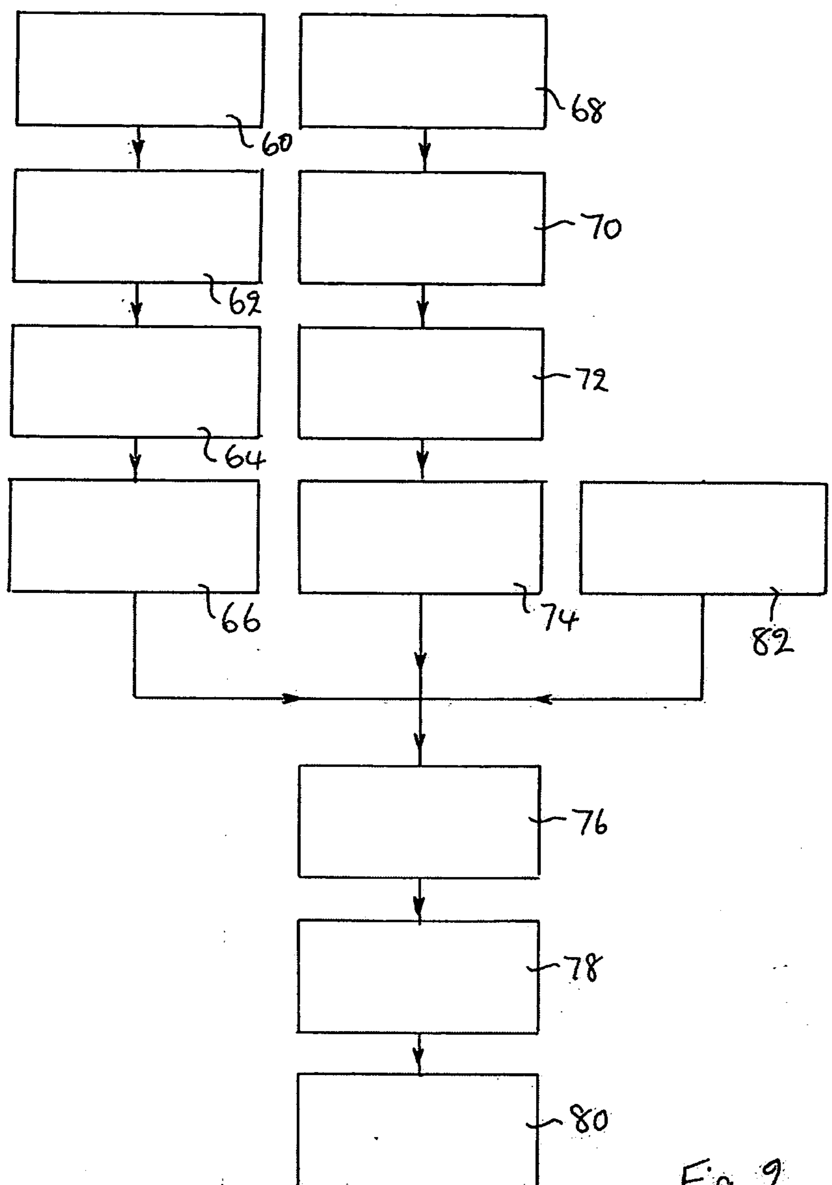
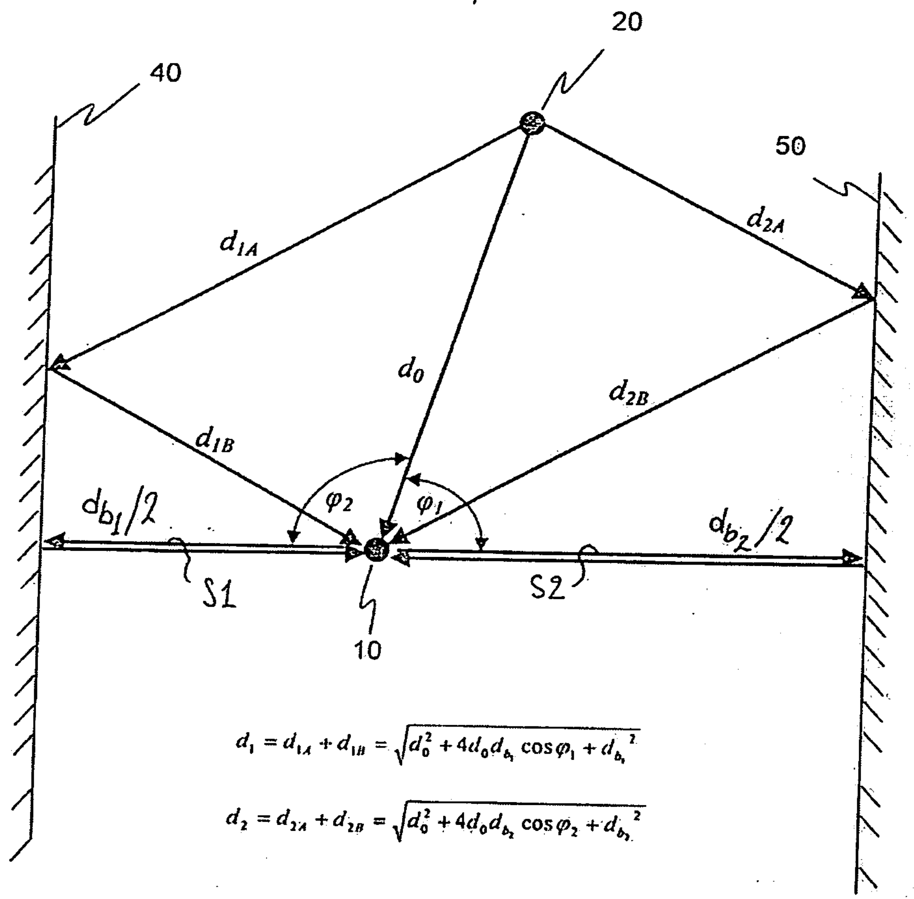


Fig. 2

PHGB 020138



$$d_1 = d_{1A} + d_{1B} = \sqrt{d_0^2 + 4d_0 d_{b_1} \cos\varphi_1 + d_{b_1}^{\,2}}$$

$$d_2 = d_{2A} + d_{2B} = \sqrt{d_0^2 + 4d_0 d_{b_2} \cos\varphi_2 + d_{b_2}^{\,2}}$$

Fig. 3

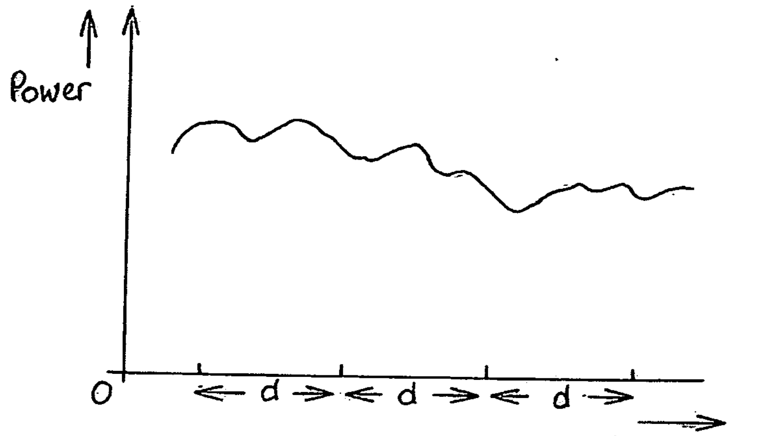

Power
0
d
d
d
Distance

Fig. 4

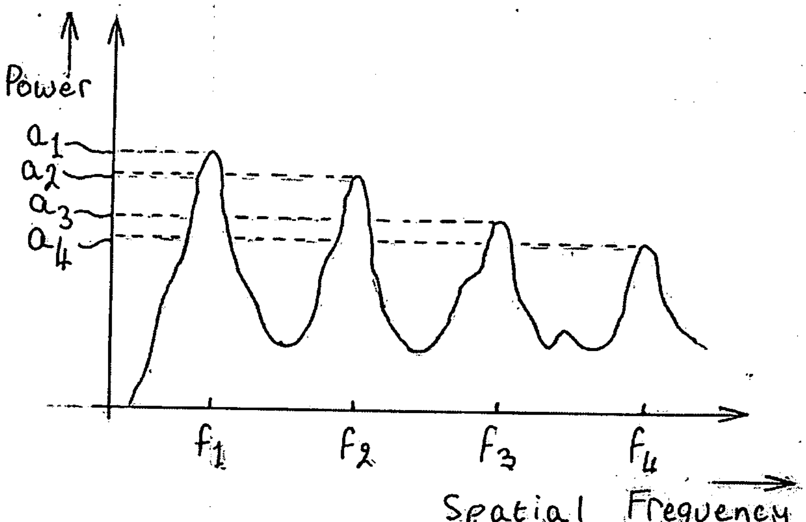

Power
a_1
a_2
a_3
a_4
f_1
f_2
f_3
f_4
Spatial Frequency

Fig. 5